Report No. NAWCADWAR-95034-4.6

# CARDIOVASCULAR RESPONSES WITH TLSS, ATAGS, AND EAGLE LIFE SUPPORT SYSTEMS DURING RAPID DECOMPRESSION

W. D. Fraser and K. N. Ackles
Aerospace Physiology Group
DEFENSE AND CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE
P.O. Box 2000
1133 Sheppard Ave., West
North York, Ontario, Canada M3M 3B9



MARCH 1995

FINAL REPORT
Period Covering January 1993 to September 1994

*Approved for Public Release; Distribution is Unlimited.*

Prepared for
NAVAL AIR SYSTEMS COMMAND (4.6T)
Department of the Navy
Washington, DC 20361-5310

NAVAL AIR WARFARE CENTER (Code 4.6C)
Warminster, PA 18974-0591

# NOTICES

**REPORT NUMBERING SYSTEM -** The numbering of technical project reports issued by the Naval Air Warfare Center, Aircraft Division, Warminster is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Functional Department responsible for the report. For example: Report No. NAWCADWAR-95010-4.6 indicates the tenth Center report for the year 1995 and prepared by the Crew Systems Engineering Department. The numerical codes are as follows.

| Code | Department |
|---|---|
| 4.1 | Systems Engineering Department |
| 4.2 | Cost Analysis Department |
| 4.3 | Air Vehicle Department |
| 4.4 | Propulsion and Power Department |
| 4.5 | Avionics Department |
| 4.6 | Crew Systems Engineering Department |
| 4.10 | Conc. Analy., Eval. and Plan (CAEP) Department |

**PRODUCT ENDORSEMENT** - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

**Reviewed By:**____________________ **Date:**________
**Author/COTR**

**Reviewed By:** G M Mitchell **Date:** 6/12/96
**LEVEL III Manager**

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. AGENCY USE ONLY** *(Leave blank)*

**2. REPORT DATE**
MARCH 1995

**3. REPORT TYPE AND DATES COVERED**
FINAL Jan 1993 – Sep 1994

**4. TITLE AND SUBTITLE**
CARDIOVASCULAR RESPONSES WITH TLSS, ATAGS, AND EAGLE LIFE SUPPORT SYSTEMS DURING RAPID DECOMPRESSION

**5. FUNDING NUMBERS**

**6. AUTHOR(S)**
W.D. FRASER and K.N. ACKLES

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Aerospace Physiology Group
DEFENSE AND CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE
P.O. Box 2000, 1133 Sheppard Ave., West
North York, Ontario, Canada M3M 3B9

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
NAVAL AIR SYSTEMS COMMAND (46T); Department of the Navy
Washington, DC 20361-5310
NAVAL AIR WARFARE CENTER (Code 46C)
Warminster, PA 18974-0591

**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
NAWCADWAR-95034-4.6

**11. SUPPLEMENTARY NOTES**
NAWCADWAR P.O.C — Barry S. Schender, Pd.D. — Code 4.6.4.1

**12a. DISTRIBUTION / AVAILABILITY STATEMENT**
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

This study compared the cardiovascular responses and degree of oxygen saturation of subjects exposed to 60,000 and 72,000 ft. rapid decompressions while wearing the U.S. Navy Enhanced Anti-G Lower Ensemble (EAGLE) and the U.S. Air Force Advanced Tactical Anti-G System (ATAGS) positive pressure breathing (PPB) ensembles. The subjects underwent the Tactical Life Support System (TLSS) integrated G-suit and PPB jerkin. Six subjects were rapidly decompressed from 22,500 to 60,000 ft. once with each of the ATAGS, EAGLE, and TLSS garments and from 35,000 ft. to 72,000 ft. once with the ATAGS and EAGLE garments. There were small but significant differences due to garment type on heart rate, stroke volume, cardiac index, and blood pressure, but all ensembles provided adequate protection against the adverse cardiovascular effects of PPB. Oxygen saturation was adequately maintained at 60,000 ft., with the TLSS garment providing the highest level of oxygenation. At 72,000 ft. the oxygen saturations of subjects wearing the ATAGS fell so rapidly that they were unable to complete a two minute exposure to 72,000 ft. Oxygen saturations were maintained at an adequate level in five of the six subjects with the EAGLE system.

**14. SUBJECT TERMS**
CARDIOVASCULAR SYSTEM, HIGH ALTITUDE, RAPID DECOMPRESSION, OXYGEN SATURATION, POSITIVE PRESSURE BREATHING

**15. NUMBER OF PAGES**

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | UNCLASSIFIED | UNLIMITED |

NAWCADWAR-95034-4.6

# CARDIOVASCULAR RESPONSES WITH TLSS, ATAGS, AND EAGLE LIFE SUPPORT SYSTEMS DURING RAPID DECOMPRESSION

W. D. Fraser and K. N. Ackles

| Accesion For | | |
|---|---|---|
| NTIS CRA&I | | X |
| DTIC TAB | | ☐ |
| Unannounced | | ☐ |
| Justification | | |
| By | | |
| Distribution / | | |
| Availability Codes | | |
| Dist | Avail and / or Special | |
| A-1 | | |

Aerospace Physiology Group
Defence and Civil Institute of Environmental Medicine
P. O. Box 2000, 1133 Sheppard Ave. West
North York, Ontario, CANADA
M3M 3B9

# Table of contents

## Abstract

This study compared the cardiovascular responses and degree of oxygen saturation of subjects exposed to 60,000 and 72,000 ft. rapid decompressions while wearing the US Navy Enhanced Anti-G Lower Ensemble (EAGLE) and the US Air Force Advanced Tactical Anti-G System (ATAGS) positive pressure breathing (PPB) ensembles. The subjects underwent an additional exposure to a 60,000 ft. rapid decompression while wearing the Tactical Life Support System (TLSS) integrated G-suit and PPB jerkin. Six subjects were rapidly decompressed from 22,500 to 60,000 ft. once with each of the ATAGS, EAGLE, and TLSS garments and from 35,000 ft. to 72,000 ft once with the ATAGS and EAGLE garments. There were small but significant differences due to garment type on heart rate, stroke volume, cardiac index, and blood pressure, but all ensembles provided adequate protection against the adverse cardiovascular effects of PPB. Oxygen saturation was adequateley maintained at 60,000 ft., with the TLSS garment providing the highest level of oxygenation. At 72,000 ft. the oxygen saturations of subjects wearing the ATAGS fell so rapdly that they were unable to complete a two minute exposure to 72,000 ft. Oxygen saturations were maintained at an adequate level in five of the six subjects with the EAGLE system.

## Introduction

The use of high levels of continuous Positive Pressure Breathing (PPB) with 100% oxygen and chest counterpressure to protect against hypoxia following rapid decompression to altitudes above 50,000 ft. has been limited in part by progressive circulatory collapse as a result of the pooling of blood in the lower extremities, a decrease in venous return, a decrease in cardiac output, and a fall in systemic blood pressure [3, 6, 7]. The application of lower body counter-pressure equal to mask and jerkin pressure can delay the onset of the circulatory collapse [7] and Ackles *et al.* [1] have confirmed Larsson and Stomblad's [14] argument that increasing the G-suit/PPB ratio pressure to 3.2 can compensate for a reduced lower body bladder coverage. Goodman *et al.* [13] have shown that a G-suit/PPB pressure ratio of 4:1 combined with the 45% greater lower body bladder coverage of the Tactical Life Support System (TLSS) provided greater protecton than the Combined Advanced Technology Enhanced Design G Ensemble (Combat Edge or CE) system against the PPB induced cardiovascular collapse. Goodman *et al.* [12] showed that 12 subjects were able to withstand 10 minutes of 88 mmHg PPB while wearing the TLSS ensemble whereas only 5 subjects could complete the 10 minutes of 88 mmHg PPB while wearing the CE ensemble. This level of protection provides a large cardiovascular safety margin during the use of PPB for protection against hypoxia following rapid decompression to 60,000 ft [10].

TLSS was not developed for operational use, though the US Navy Enhanced Anti-G Lower Ensemble (EAGLE) and the USAF Advanced Tactical Anti-G System (ATAGS) ensembles are being considered for use in the operational environment for improving Gz protection. Though not explicitly designed for

protection against the severe hypoxia following rapid decompression above 50,000 ft., the extended lower body coverage provided by these garments should be as, or more effective than CE and TLSS in providing protection against the adverse effects of positive pressure breathing following rapid decompression and thus be suitable for providing altitude protection. This study was undertaken to examine the effectiveness of the ATAGS and EAGLE ensembles in providing protection from the hypoxic stress of rapid decompression to 60,000 and 72,000 ft. and to examine the degree of cardiovascular compromise induced by the use of PPB.

## Methods

### *Subjects*

Two female and four male subjects took part in this experiment. All subjects gave written, informed consent in accordance with the guidelines of the DCIEM Human Ethics Committee and had passed the DCIEM medical examination for positive pressure breathing experiments. Their physical characteristics are given in Table 1. All had extensive experience with positive pressure breathing at up to 80 mmHg. Five of the six subjects have had extensive experience with rapid decompression up to 72,000 ft.

## Table 1.
## Physical Characteristics of Subjects

| Subject | Sex | Age | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| ael | F | 29 | 166 | 63 |
| jsm | M | 37 | 178 | 72 |
| mms | F | 30 | 166 | 55 |
| mrp | M | 31 | 178 | 76 |
| twg | M | 25 | 193 | 89 |
| wdf | M | 40 | 187 | 99 |

*Techniques*

During the experiments the subject's blood pressure was monitored with a Finapres 2300 blood pressure waveform monitor (Ohmeda 2300, Canadian Oxygen Ltd., Rexdale, Ontario) with the blood pressure cuff on the left ring finger and the hand supported at heart level with a sling. Cardiac impedance waveforms were generated and monitored with a Minnesota Impedance Cardiograph, Model 304B (Surcom Inc. Minneapolis, Minn.) using two neck and two torso band electrodes [5]. The electrocardiogram was monitored with a modified Lead II configuration and a ECG amplifier (Model 13-415-58, Gould Inc., Instruments Division, Cleveland, Ohio). Mask cavity pressure was measured with a pressure transducer (Model PS309, Validyne Corp., Northridge, CA) and chamber altitude was monitored with a an altimeter (Pennwalt, Model 61C-1D-08006, Wallace and Ternman, Bellville, NJ). Oxygen saturation was monitored with a pulse Oximetre (Radiometre, Copenhagen, Denmark) with the probe on the right index finger. The right hand was supported with a sling at heart level.

*Procedures*

Each of the subjects was exposed to 22,500 ft. to 60,000 ft. rapid decompressions, with 70 mmHg PPB, while wearing the ATAGS, EAGLE, and TLSS ensembles, and 35,000 ft. to 72,000 ft. mmHg rapid decompressions, with 80 mmHg of PPB, while wearing the ATAGS and EAGLE garments. All subjects wore the G-suit booties with the ATAGS garment.

Prior to each experiment a finger-tip blood sample was taken for the measurement of hematocrit and body weight was recorded. ECG and impedance electrodes were attached and the subjects fitted with one of the three PPB ensembles. The subjects were then seated in the DCIEM altitude chamber and connected to the display and computer acquisition equipment. The subject sat in an ejection type seat and breathed 100% oxygen at ground level for at least 1 hour prior to commencing the experiment to minimize the risk of decompression sickness. Chamber pressure was reduced from ground level to an altitude equivalent of 22,500 ft. Control physiological data was collected for 3 minutes at this altitude. Chamber pressure was then decreased to an altitude equivalent of 35,000 ft. and maintained at that level for up to 3 minutes for the passing of gastrointestinal gas. For the 60,000 ft. experiments the chamber was then recompressed to the 22,500 ft. and the subject was rehearsed on the rapid decompression procedure. A Canadian Forces Aeromedical Technician was present in the altitude chamber with the subject prior to the rapid decompression from 22,500 ft., remaining in the chamber air lock during the excursion to 35,000 ft. and the rapid decompression. The subject was instructed to exhale during a 5 second countdown, and rapid decompression of the

chamber from 22,500 ft. to 60,000 ft. was completed in less than 0.6 s. Positive pressure in the mask and chest jerkin was controlled by a Clifton Precision Breathing Regulator Anti-G (BRAG) valve. Inflation of the G-suit was initiated by the run director simultaneously with the rapid decompression. The PPB level at 60,000 ft. was maintained at 70 mmHg with the G-suit pressure at 280 mmHg. Subjects remained at altitude for 3 minutes or until the oxygen saturaraton fell below 65%, or the subject, the run director, or the medical officer requested a termination of the exposure. Subjects were then recompressed to 35,000 ft. at 20,000 ft. per minute and then to ground level .

For the 72,000 ft. decompression subjects were rehearsed in the rapid decompression procedure during the hold at 35,000 ft. Rapid decompression to 72,000 ft, was then initiated from this altitide. The PPB level at 72,000 ft. was maintained at 80 mmHg with the G-suit pressure at 320 mmHg. Maximum exposure duration at this altitude was 2 minutes followed by descent to ground level.

Each subject was tested on 5 different days with at least 48 hours between exposures. Order of exposures were randomized.

*Physiological parameters*

Electrocardiogram (ECG), Finapres blood pressure waveforms, cardiac impedance dz/dt and Zo waveforms, oxygen saturation and mask and suit pressures were recorded during the three minute control period and during the rapid decompression directly to computer disk with a Macintosh IIci (Apple Computer Corp. Cupertino, CA) computer running the LabViews™ data collection and analysis package (National Instruments, Austin, TX) at a

sampling rate of 100 Hz. The data was transferred via LAN to a Macintosh IIx computer. In-house UNIX based processing software was used to automatically analyze all waveform data and calculate heart rate, stroke volume, cardiac index, and blood pressure on a beat-by-beat basis and oxygen saturation on a continuous basis. See [11] for details. Fifteen second averages of these parameters were calculated and transferred to the statistical package for further analysis.

*Statistical analysis*

A 1 factor (garment) by 1 regressor (time following rapid decompression) analysis of covariance (ANCOVA) was used to analyze the heart rate, blood pressure, stroke volume, cardiac index, and oxygen saturation data. Fifteen second averages of each parameter minus the mean value of the parameter over the 3 minutes of control were calculated and used in the statistical analysis. The general linear modeling (GLM) package SuperAnova (Abacus Concepts Inc. Berkeley, CA) running on a Macintosh IIx (Apple Computer Corp. Cupertino, CA) was used for all calculations. Main effects and interactions were deleted if they were not significant at the $P < 0.05$ level and the analysis was repeated.

## Results

Figure 1 and 2 show the changes in the oxygen saturation following the rapid decompression for the ATAGS, EAGLE, and TLSS garments. Figures 3 - 6 show the cardiovascular responses following rapid decompression. All data is presented as changes during rapid decompression with respect to the average of

the three minute control periods prior to rapid decompression. Error bars represent SEM.

Appendix B. contains the tables of all the individual changes in cardiac parameters and oxygen saturation that occurred during positive pressure breathing. All parameters are expressed as absolute change from the average value of the parameter during the three minute control period prior to the onset of the positive pressure breathing. Values are averaged over 15 s intervals. Missing cells represent bad data or failure of the subject to complete the full 20 minutes of PPB exposure.

The $SaO_2$ fell rapidly following the rapid decompression similar to that obsevered in previous studies [4,9,13]. The final level of $SaO_2$ after the 3 minutes at 60,000 ft. for both systems was in the range expected given the results of previous rapid decompression studies with similar levels of PPB [4, 10, 14]. For $SaO_2$ following the rapid decompressions there was a significant effect of time following rapid decompression ($F = 41$, $P < 0.0001$) and altitude ($F = 48$, $P < 0.0001$), but no overall effect of garment type. There was a significant interaction between garment and time following rapid decompression ($F = 5$, $P < 0.006$) and garment, altitude/PPB, and time following rapid decompression ($F = 6$, $P < 0.004$). For the 60,000 ft. rapid decompression, $SaO_2$ was maintained the best over time with the ATAGS garment while the greatest fall in $SaO_2$ occurred with subjects wearing the EAGLE garment (Figure 1). However, during the 72,000 ft. exposures a more rapid fall in $SaO_2$ occurred with the ATAGS garment (Figure 2). In addition five of the six runs with ATAGS at 72,000 ft had to be terminated prior to the completion of the two minute altitude exposure. Only one of the EAGLE runs was terminated prematurely.

All three garments provided a high level of cardiovascular support with only small, but statistically significant differences in heart rate ($F = 6$, $P < 0.04$) and stroke volume ($F = 16$, $P < 0.0001$) during the rapid decompression exposures. The increase in heart rate compensated for the falls in stroke volume resulting in no change in the cardiac index during the rapid decompression. There was a significant change in systolic blood pressure over time ($F = 18$, $P < 0.0001$), but no effect due to altitude or garment type.

## Discussion

The extended lower bladder coverage of all three garments was more than sufficient to ameloriate the adverse effects of PPB on cardiovascular function during the short exposures following rapid decompression. This is entirely expected given that subjects can tolerate more than 10 minutes of PPB at ground level with any of the three garments [11].

In a previous study [9] we observed a statistically significant difference in the oxygen saturation with the TLSS and CE garments during rapid decompression, with the $SaO_2$ falling further with the TLSS garment following rapid decompression to 60,000 ft. In this study $SaO_2$ was maintained to a better degree with TLSS than with ATAGS or EAGLE at 60,000 ft. Although the saturation differerence between the three systems was only 6% $SaO_2$ at the end of the three minutes of exposure this could be critical at these levels of hypoxic stress. However, at 72,000 ft. the differences between the $SaO_2$ with the ATAGS and EAGLE garments was substantial, with a very rapid drop in the $SaO_2$ following decompression when the subjects wore the ATAGS garment. The differences in $SaO_2$ may be due to the interaction between the different levels of lower body bladder coverages and the known effects of PPB on V/Q relationships in the lung [16]. The inability of five of the six subjects to complete their ATAGS runs at 72,000 ft. due to this extremely rapid fall in $SaO_2$ would indicate that the ATAGS garment is not suitable for providing emergency protection at this extreme altitude.

The differences in $SaO_2$ response for subjects wearing the different garments in this and the previous study [10] may be artifact due to differences in venous

congestion in the arm and hand on which the oximeter probe is attached. This venous congestion may be a consequence of the differences in lower body bladder coverage. This effect would have to include the head as in several of our runs the rapid fall in $SaO_2$ with the ATAGS garment at 72,000 ft. was confirmed with an ear-lobe oximeter.

The advantage of using high levels of PPB for prevention of hypoxia following rapid decompressions at extreme altitudes is well established [3, 4, 9, 13]. Given the lack of a current operational capability or requirement for operations above 50,000 ft. the usefullness of very high levels of PPB for emergency altitude protection is limited. However since we have established that PPB duration can be extended well beyond 15 minutes [11] there may be considerable utility in using PPB to increase internal body pressure and thus reduce the risk of decompression sickness following loss of canopy pressure at altitudes where hypoxia is not the most significant problem. Bubble formation and growth is strongly dependent on the hydrostatic pressure of the fluid in which bubbles can occur [17,18]. Any increase in this pressure will reduce the likelihood of nucleation and subsequent bubble growth. At present, with the loss of cockpit pressurization at altitudes above 35,000 ft., pilots will normally breathe 100% $O_2$ at a pressure of 30 mmHg. For a pilot at 45,000 ft this reduces her effective physiological altitude to 40,000 ft. If instead the pilot breathed oxygen at 80 mmHg, the physiological altitude would then be reduced to less than 34,000 ft. The extended bladder coverage provided by these newer G-suit designs may make this a practical and safe procedure for reducing the risk of decompression sickness and allow for mission completion in spite of a loss of cockpit pressurization. However, additional research is needed to investigate the combined effects of long-duration PPB and moderate hypoxia stress on the

cardiovascular system. Given the substantial differences among the ensembles in maintaining $SaO_2$ at the extreme altitudes, additional work is required to determine the optimal design of G-suit/chest counter-pressure jerkin to optimize oxygen delivery, minimize cardiovascular decrements, and minimze the risk of decompression sickness during long exposures to altitude stress.

## ACKNOWLEDGMENTS

This study was supported by the Naval Air Warfare Center, Waminster. PA. in collaboration with the Gentex Corp., Carbondale, PA. The authors wish to thank the subjects partaking in the experiment, the personnel of the Experimental Diving Unit, the School of Aerospace Medicine, the Central Medical Board, and the Life Support Equipment Group. We also wish to thank Lt. Col. Ron Hill, Lt. Col. Tom Morgan and other personnel of the Armstrong Laboratories (Brooks AFB) for the loan of the ATAGS garments and an additional BRAG regulator, Mr. Harvey Jagoe and Dr. Lew Epperson of Gentex Corporation, and Dr. Phil Whitley and Dr. Barry Shender of NAWC, Warminster. We also would like to acknowledge the technical assistance of Mr. Tom Gee, Mr. Barry Kelso, Mr. Marty Pecaric, Mr. Jim Maloan, and Sgt. Ray Smith.

## References

1. Ackles, K. N. *et al.* Protection against the physiological effects of positive pressure breathing. *Aviat. Space Environ. Med.*, 1978. **49**: p. 753 - 758.

2. Anderson D. P. *et al.* Circu!atory changes during fainting and coma caused by oxygen lack. *J. Physio l*. 1946. **104**: p426 - 431.

3. Bazett H. C, and G. R. MacDougall. Pressure Breathing and Altitude - Practical method for its use. Associate Committee on Aviation Medicine Research of the Natonal Research Council of Canada. 1942.

4. Buick, F. and J. A. G. Porlier. Oxyhemoglobin saturation following rapid decompression to 18,288 m preceded by diluted oxygen breathing. *Aviat. Space Environ. Med.*, 1991. **62**(12): p. 1119-1126.

5. Denniston, J. C., *et al.* Measurement of cardiac output by electrical impedance at rest and during exercise. *J. Appl. Physiol.*, 1976. **40**: p. 91-95.

6. Ernsting J. The Physiology of Pressure Breathing in *A Textbook of Aviation Medicine*, J.A. Gims, Editor. 1965. Permagon Press: Oxford. p343-373.

7. Ernsting J, Some effects of raised intrapuimonary pressure in man. AGARDograph. 1966. NATO.

8. Ernsting, J., *et al.*. High altitude protection from pressure-breathing mask with trunk and lower limb counterpressure. *Aerosp. Med.*, 1960. **31**: p. 41-48.

8. Folkow B. and J. R. Pappenheimer. Components of the respiratory dead space and their variations with pressure breathing and with bronchioactive drugs. *J. Appl. Physiol.* 1955; **8**: p. 133-138.

9. Fraser, W. D., *et al.*, Cardiovascular responses with standard and extended bladder coverage G-suits during rapid decompression. *Aviat. Space Environ. Med.*, 1994. **65**: p. 209-213.

10. Fraser, W. D. and K. N. Ackles. Cardiovascular responses to very long duration positive pressure breathing. (In preparation). *Aviat. Space Environ. Med.*, 1994. **65**: p. 209-213.

11. Goodman, L. S. *et al.*, Effect of extending G-suit coverage on cardiovascular responses to positive pressure breathing. *Aviat. Space Environ. Med.*, 1993. **64**: p. 1101-1107.

12. Goodman, L. S., *et al.*, Cardiovascular responses to positive pressure breathing using the Tactical Life Support System. *Aviat. Space Environ. Med.*, 1992. **63**: p. 662-669.

13. Holness D. E. *et al.* Respiratory gas exchange during positive pressure breathing and rapid decompression to simulated altitudes of 18.3 and 24.4 km. Aviat. Space Environ. Med. 1980. **51**: p454-458.

14. Larsson L. E. and Stromblad C. R. Development of a flying support system for the RSAF. Forvarsmed. 1967. **3**:17-26.

15. Tenney S. M. and C. R. Honig. Reversal of normal respiratory variation and change in thoracic blood volume. Aviat. Med. 1955. p194-199.

16. Ward, C. A., P. Tikuisis, and R. D. Venter, Stability of bubbles in a closed volume of liquid-gas solution. *J. of Appli. Physiol.*, 1982. **53**(9): p. 6076-6084.

17. Ward, C.A., A.S. Tucker, and C.W. So, A bubble evolution method for diffusion coefficient measurements utilizing critical size concept. J. *Physi. Chem.*, 1979. **53**: p. 543-550.

# Figures

## Figure captions

### Figure 1.

Changes in percentage oxygen saturation ($SaO_2$) following rapid decompression to 60,000 ft. The change in $SaO_2$ is calculated with respect to the average $SaO_2$ over the three minutes of the control period.

### Figure 2.

Changes in percentage oxygen saturation ($SaO_2$) following rapid decompression to 72, 000 ft. The change in $SaO_2$ is calculated with respect to the average $SaO_2$ over the three minutes of the control period. Data was available for the full two minutes from only one subject wearing the ATAGS garment.

### Figure 3.

Changes in heart rate for the different garments. The change in heart rate is calculated with respect to the average heart rate over the three minutes of the control period. Results from both altitude/PPB levels, all times, and all subjects are collapsed together to show the main effect of garment.

### Figure 4.

Changes in stroke volume for rapid decompressions to 60,000 ft. (PPB of 70 mmHg) and 72,000 ft. (PPB of 80 mmHg). The change in stroke volume is calculated with respect to the average stroke volume over the three minutes of the control period at 22,500 ft or 35,000 ft. Results over time are collapsed together to show the significant main effects of altitude/PPB level and garment.

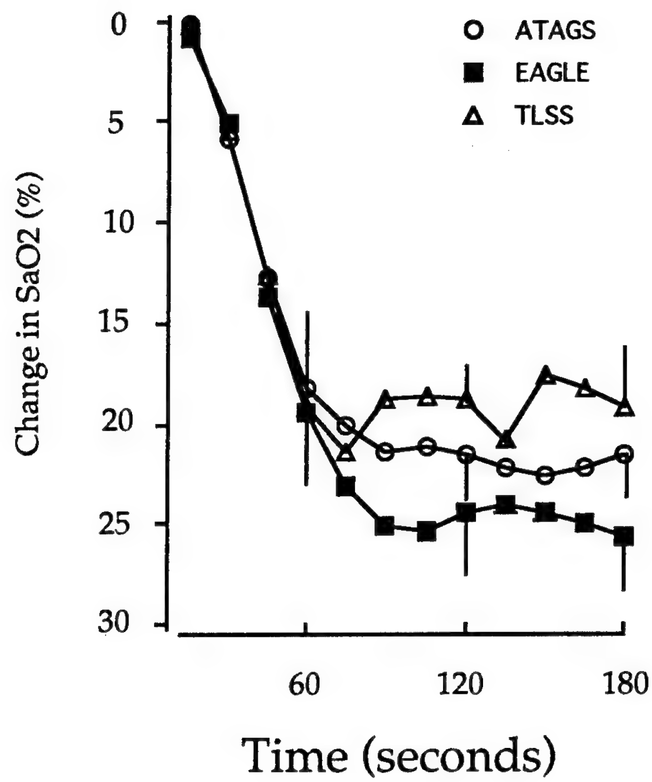
**Figure 5.**

Changes in systolic blood pressure as a function of altitude/PPB level and garment. The change in systolic blood pressure is calculated with respect to the average systolic blood pressure over the three minutes of the control period prior to the onset of rapid decompression. The results are collapsed over all time.

**Figure 6.**

Changes in systolic blood pressure as a function of time for different garments for rapid decompressions to 60,000 ft. (PPB of 70 mmHg). The change in systolic blood pressure is calculated with respect to the average systolic blood pressure over the three minutes of the control period prior to the onset of RD.

**Figure 1.**


0
5
10
15
20
25
30
Change in SaO2 (%)
ATAGS
EAGLE
TLSS
60
120
180
Time (seconds)

# Figure 2.

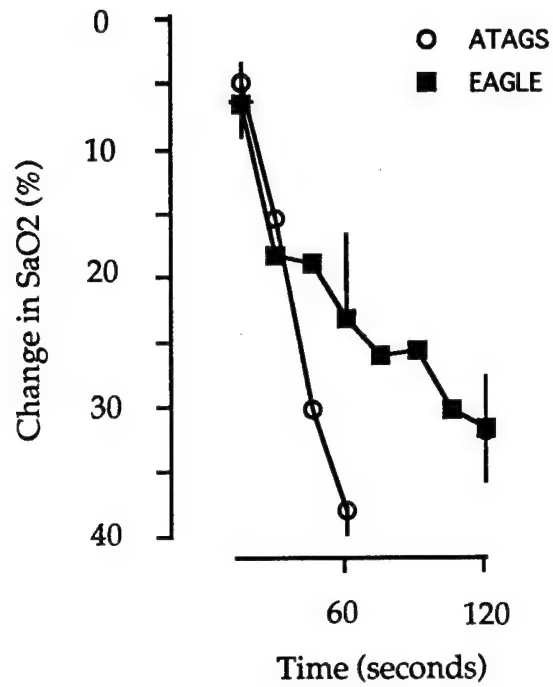
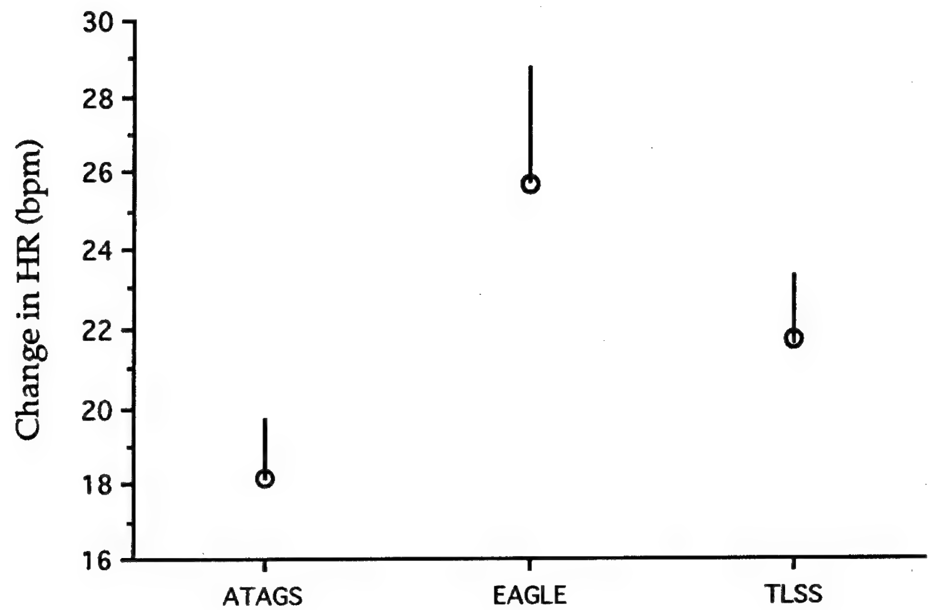


**Figure 3.**



# Figure 4.

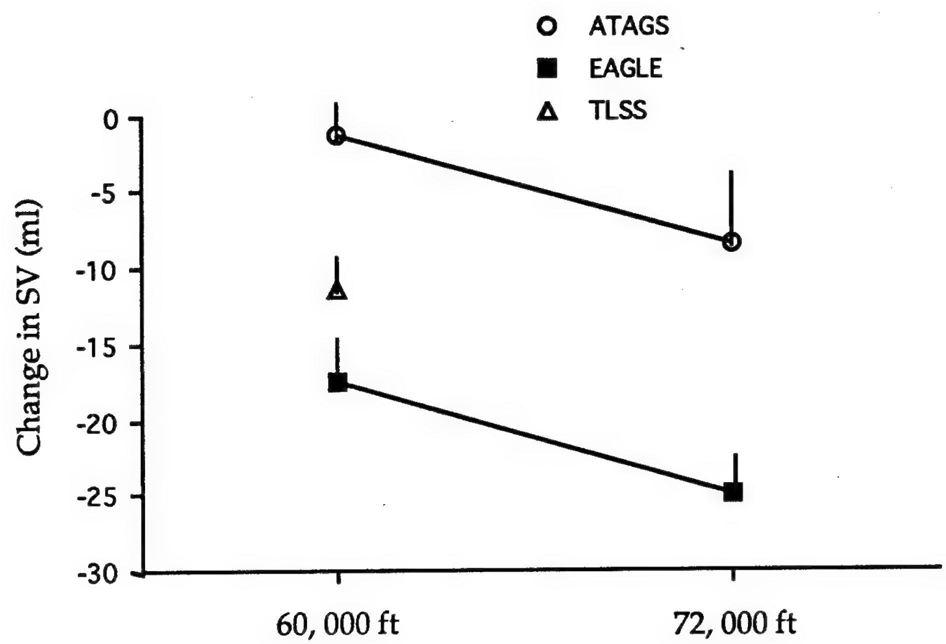

ATAGS
EAGLE
TLSS
0
-5
-10
-15
-20
-25
-30
Change in SV (ml)
60, 000 ft
72, 000 ft

Figure 5.

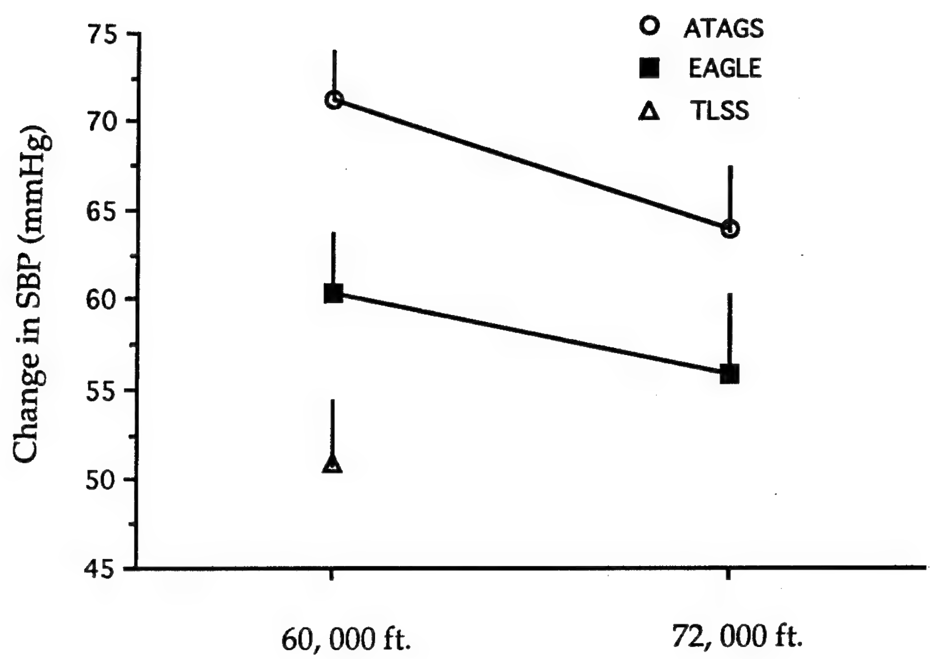
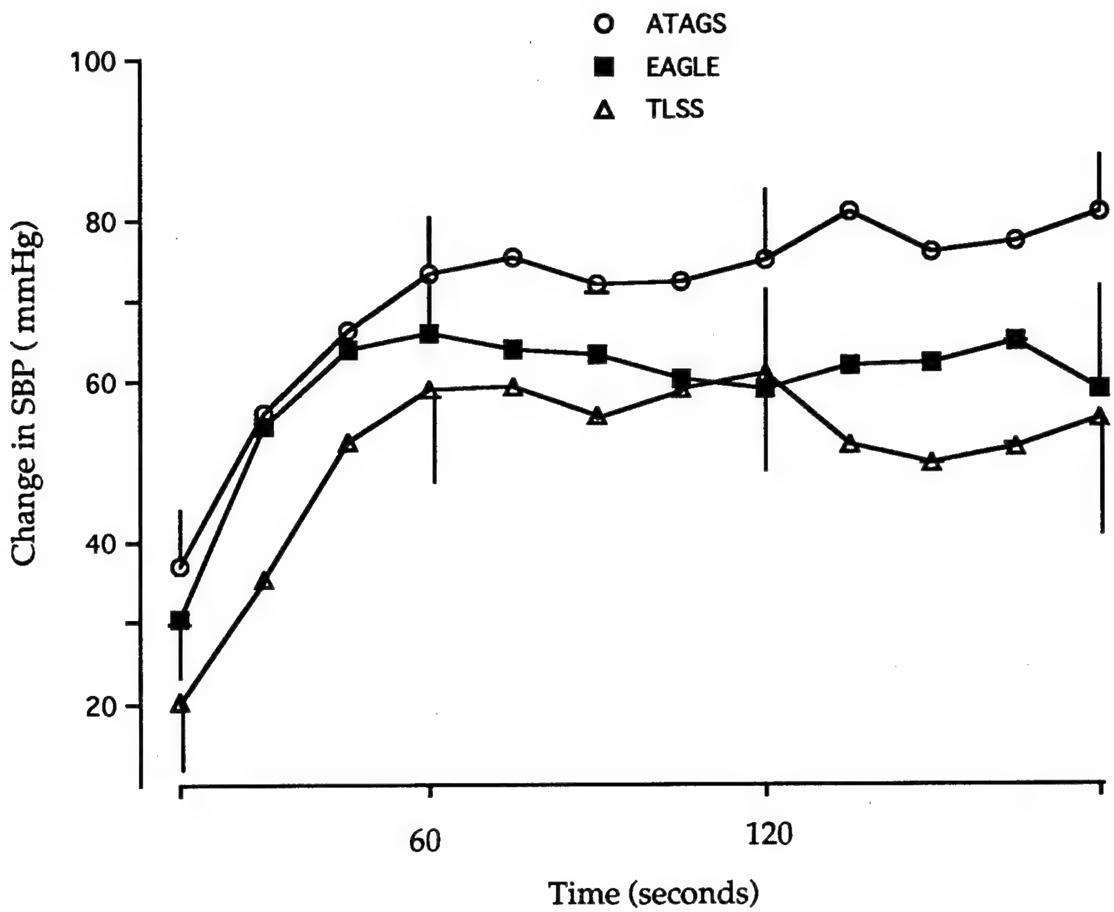

ATAGS
EAGLE
TLSS
Change in SBP (mmHg)
75
70
65
60
55
50
45
60, 000 ft.
72, 000 ft.

**Figure 6.**


ATAGS
EAGLE
TLSS
100
80
60
40
20
Change in SBP ( mmHg)
60
120
Time (seconds)

# Appendix B.

## Calculated change in cardiac indices for each subject

### Key

| | |
|---|---|
| HR | Heart rate (bpm) |
| SV | Stroke volume (ml) |
| CI | Cardiac index ($l/min/m^2$) |
| SBP | Systolic blood pressure (mmHg) |
| DBP | Diastolic blood pressure (mmHg) |
| $SaO_2$ | Oxygen saturation (%) |

All parameters are expressed as absolute change from the average value of the parameter during the three minute control period prior to the onset of rapid decompression. Values are averaged over 15 s intervals. Missing cells represent bad data or failure of the subject to complete the full altitude exposure.

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** ATAGS
**Subject** ael

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 43 | -22 | 0.03 | 15 | 61 | 0 |
| | 30 | 39 | -10 | 0.02 | 42 | 76 | -10 |
| | 45 | 39 | -24 | 0.01 | 61 | 82 | -14 |
| | 60 | 27 | -21 | -0.02 | 75 | 86 | -15 |
| | 75 | 25 | -3 | 0.00 | 82 | 84 | -14 |
| | 90 | 43 | -41 | -0.02 | 87 | 91 | -14 |
| | 105 | 43 | -36 | -0.03 | 92 | 94 | -15 |
| | 120 | 33 | -33 | -0.03 | 103 | 94 | -15 |
| | 135 | 15 | -25 | -0.02 | 109 | 96 | -14 |
| | 150 | 9 | -29 | -0.04 | 105 | 95 | -15 |
| | 165 | 22 | -30 | -0.02 | 107 | 99 | -16 |
| | 180 | 12 | -10 | -0.01 | 101 | 93 | -16 |
| **72,000 ft.** | 15 | 11 | 3 | 0.02 | 42 | 79 | -10 |
| | 30 | -11 | -1 | -0.02 | 72 | 85 | -15 |
| | 45 | -8 | -5 | -0.03 | 77 | 82 | -22 |
| | 60 | -13 | -10 | -0.04 | 78 | 81 | -44 |
| | 75 | -8 | -8 | -0.03 | 86 | 85 | -29 |
| | 90 | -1 | -21 | -0.04 | 85 | 85 | -30 |
| | 105 | 8 | -28 | -0.04 | 95 | 91 | -29 |
| | 120 | 16 | -35 | -0.04 | 93 | 88 | -32 |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** EAGLE
**Subject** ael

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 31 | -9 | 0.02 | 51 | 64 | -1 |
| | 30 | 7 | -5 | 0.00 | 98 | 80 | -9 |
| | 45 | -7 | 2 | -0.01 | 102 | 79 | -11 |
| | 60 | -7 | 2 | 0.00 | 96 | 76 | -14 |
| | 75 | 23 | -15 | 0.00 | 81 | 74 | -14 |
| | 90 | 44 | -29 | -0.02 | 80 | 80 | -17 |
| | 105 | 45 | -31 | -0.03 | 90 | 87 | -18 |
| | 120 | 45 | -26 | -0.01 | 96 | 92 | -18 |
| | 135 | 33 | -28 | -0.03 | 97 | 91 | -18 |
| | 150 | 41 | -31 | -0.03 | 94 | 94 | -21 |
| | 165 | 50 | -34 | -0.03 | 101 | 100 | -21 |
| | 180 | 46 | -35 | -0.03 | 95 | 93 | -21 |
| **72,000 ft.** | 15 | 12 | • | • | 26 | 63 | -4 |
| | 30 | -28 | • | • | 63 | 74 | -18 |
| | 45 | 46 | • | • | 80 | 75 | -24 |
| | 60 | 33 | -29 | -0.07 | 90 | 79 | -23 |
| | 75 | • | • | • | 99 | 83 | -24 |
| | 90 | • | • | • | 96 | 82 | -27 |
| | 105 | 20 | • | 0.13 | 94 | 81 | -31 |
| | 120 | 26 | • | 0.15 | 88 | 77 | -34 |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** TLSS
**Subject** ael

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 34 | 4 | 0.05 | 16 | 50 | • |
| | 30 | 31 | -15 | 0.02 | 58 | 69 | -6 |
| | 45 | 36 | -27 | 0.00 | 71 | 71 | -11 |
| | 60 | 20 | -12 | 0.01 | 85 | 72 | -13 |
| | 75 | 27 | -27 | -0.01 | 95 | 76 | -14 |
| | 90 | 35 | -33 | -0.02 | 90 | 78 | -16 |
| | 105 | 36 | -37 | -0.02 | 91 | 79 | -17 |
| | 120 | 32 | -36 | -0.03 | 87 | 74 | -20 |
| | 135 | 35 | -33 | -0.02 | 84 | 71 | -21 |
| | 150 | 28 | -34 | -0.03 | 93 | 77 | -21 |
| | 165 | 31 | -39 | -0.04 | 91 | 78 | -21 |
| | 180 | 20 | -32 | -0.03 | 86 | 70 | -22 |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** ATAGS
**Subject** jsm

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 13 | 10 | 0.03 | 35 | 39 | 0 |
| | 30 | 16 | 8 | 0.02 | 56 | 51 | -1 |
| | 45 | 6 | 21 | 0.03 | 68 | 55 | -7 |
| | 60 | -3 | 20 | 0.02 | 67 | 58 | -8 |
| | 75 | -3 | 20 | 0.02 | 75 | 58 | -12 |
| | 90 | 6 | 8 | 0.01 | 76 | 60 | -16 |
| | 105 | 7 | -3 | 0.00 | 77 | 61 | -16 |
| | 120 | 6 | 6 | 0.01 | 76 | 63 | -16 |
| | 135 | 0 | 7 | 0.00 | 76 | 63 | -16 |
| | 150 | 9 | 1 | 0.00 | 77 | 64 | -16 |
| | 165 | 2 | 10 | 0.01 | 75 | 63 | -18 |
| | 180 | 4 | 12 | 0.01 | 79 | 65 | -14 |
| **72,000 ft.** | 15 | 21 | 27 | 0.06 | 30 | 34 | -2 |
| | 30 | 23 | 26 | 0.06 | 54 | 47 | -9 |
| | 45 | 9 | • | 0.14 | 54 | 55 | -28 |
| | 60 | 13 | 56 | 0.10 | 65 | 58 | -32 |
| | 75 | 16 | 40 | 0.09 | 77 | 57 | -37 |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** EAGLE
**Subject** jsm

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| 60,000 ft | 15 | 26 | -4 | 0.02 | 71 | 53 | 1 |
| | 30 | 22 | -9 | 0.01 | 95 | 58 | 3 |
| | 45 | 23 | -11 | 0.01 | 91 | 63 | -8 |
| | 60 | 20 | -10 | 0.01 | 103 | 68 | -18 |
| | 75 | 22 | -9 | 0.01 | 99 | 66 | -26 |
| | 90 | 26 | -16 | 0.02 | 95 | 68 | -23 |
| | 105 | 25 | -13 | 0.00 | 101 | 70 | -21 |
| | 120 | 21 | -12 | 0.00 | 100 | 71 | -19 |
| | 135 | 24 | -14 | 0.00 | 86 | 72 | -19 |
| | 150 | 28 | -13 | 0.01 | 91 | 72 | -18 |
| | 165 | 26 | -16 | 0.02 | 95 | 74 | -18 |
| | 180 | 24 | -2 | 0.03 | 78 | 69 | -17 |
| 72,000 ft. | 15 | 38 | -22 | 0.02 | 34 | 42 | -2 |
| | 30 | 25 | -14 | 0.00 | 44 | 48 | -1 |
| | 45 | 26 | -8 | 0.01 | 46 | 51 | -1 |
| | 60 | 27 | -13 | 0.01 | 51 | 56 | -1 |
| | 75 | 27 | -19 | -0.01 | 37 | 48 | -3 |
| | 90 | 26 | -19 | 0.02 | 34 | 49 | -14 |
| | 105 | 41 | -13 | 0.02 | 10 | 26 | -17 |
| | 120 | 42 | -14 | 0.02 | 7 | 27 | -21 |

## Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** TLSS
**Subject** jsm

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 30 | -1 | 0.02 | 29 | 53 | 0 |
| | 30 | 30 | -2 | 0.02 | 35 | 58 | 0 |
| | 45 | 27 | -4 | 0.01 | 60 | 63 | -6 |
| | 60 | 11 | 18 | 0.02 | 65 | 68 | -13 |
| | 75 | -4 | 16 | 0.01 | 64 | 66 | -16 |
| | 90 | 12 | 3 | 0.01 | 68 | 68 | -16 |
| | 105 | 16 | 4 | 0.02 | 84 | 70 | -16 |
| | 120 | 22 | 0 | 0.01 | 82 | 71 | -18 |
| | 135 | 3 | -2 | 0.01 | 64 | 72 | -27 |
| | 150 | 11 | -5 | 0.00 | 60 | 72 | -13 |
| | 165 | 17 | 2 | 0.01 | 66 | 74 | -12 |
| | 180 | 11 | -2 | 0.01 | 85 | 69 | -13 |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** ATAGS
**Subject** mms

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | -5 | 9 | 0.01 | 37 | 42 | |
| | 30 | -2 | 5 | 0.01 | 56 | 58 | -7 |
| | 45 | 12 | -2 | 0.00 | 72 | 67 | -13 |
| | 60 | 2 | 0 | 0.00 | 79 | 68 | -20 |
| | 75 | 0 | 2 | 0.00 | 85 | 73 | -23 |
| | 90 | -2 | 2 | 0.00 | 80 | 68 | -23 |
| | 105 | 7 | -6 | 0.00 | 81 | 70 | -24 |
| | 120 | 4 | -1 | 0.01 | 81 | 71 | -24 |
| | 135 | 1 | -2 | 0.00 | 80 | 69 | -25 |
| | 150 | 3 | -7 | 0.00 | 68 | 65 | -24 |
| | 165 | 4 | -7 | -0.01 | 70 | 66 | -25 |
| | 180 | 2 | -2 | 0.00 | 72 | 67 | -24 |
| **72,000 ft.** | 15 | 38 | • | • | 45 | 45 | -4 |
| | 30 | 26 | • | • | 49 | 54 | -23 |
| | 45 | 58 | • | • | 62 | 57 | -35 |
| | 60 | 53 | • | • | 67 | 57 | -36 |
| | 75 | • | • | • | • | • | • |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** EAGLE
**Subject** mms

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 3 | 13 | 0.03 | 19 | 30 | 0 |
| | 30 | 11 | -4 | 0.01 | 33 | 42 | -10 |
| | 45 | 10 | -7 | 0.00 | 45 | 51 | -24 |
| | 60 | 9 | -12 | -0.01 | 47 | 51 | -24 |
| | 75 | 9 | -8 | -0.01 | 43 | 44 | -30 |
| | 90 | 17 | -9 | 0.01 | 42 | 39 | -33 |
| | 105 | 16 | -12 | 0.00 | 40 | 40 | -31 |
| | 120 | 16 | -13 | -0.01 | 31 | 34 | -31 |
| | 135 | 10 | -10 | -0.01 | 26 | 27 | -30 |
| | 150 | 9 | -4 | 0.00 | 19 | 22 | -29 |
| | 165 | 15 | -10 | 0.00 | 17 | 19 | -29 |
| | 180 | 5 | 2 | 0.01 | 10 | 16 | -29 |
| **72,000 ft.** | 15 | 38 | 5 | 0.01 | 50 | 60 | -8 |
| | 30 | 26 | -24 | -0.03 | 73 | 72 | -23 |
| | 45 | 58 | -39 | -0.06 | 81 | 78 | -26 |
| | 60 | 53 | -34 | -0.06 | 80 | 74 | -31 |
| | 75 | 47 | -11 | -0.05 | 75 | 70 | -30 |
| | 90 | 50 | -30 | -0.05 | 78 | 70 | -31 |
| | 105 | 22 | -39 | -0.06 | 68 | 63 | -30 |
| | 120 | 14 | -21 | -0.04 | 63 | 64 | -30 |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** TLSS
**Subject** mms

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| 60,000 ft | 15 | -3 | 11 | 0.01 | 21 | 28 | 0 |
| | 30 | -6 | 14 | 0.02 | 25 | 32 | -4 |
| | 45 | -1 | 13 | 0.01 | 39 | 41 | -11 |
| | 60 | 1 | 1 | 0.01 | 51 | 45 | -18 |
| | 75 | 2 | -2 | 0.00 | 45 | 43 | -20 |
| | 90 | 7 | -5 | 0.00 | 31 | 34 | -21 |
| | 105 | 15 | -8 | 0.00 | 36 | 34 | -21 |
| | 120 | 6 | -1 | 0.00 | 49 | 41 | -18 |
| | 135 | 4 | -1 | 0.00 | 42 | 35 | -19 |
| | 150 | 12 | -7 | 0.00 | 31 | 30 | -18 |
| | 165 | -6 | -1 | -0.01 | 28 | 26 | -19 |
| | 180 | 13 | -1 | 0.01 | 25 | 24 | -19 |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** ATAGS
**Subject** mrp

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 48 | -20 | 0.05 | 78 | 71 | -1 |
| | 30 | • | • | • | 96 | 82 | -8 |
| | 45 | • | • | • | 98 | 85 | -16 |
| | 60 | • | • | • | 101 | 84 | -20 |
| | 75 | • | • | • | 100 | 88 | -24 |
| | 90 | • | • | • | • | • | -25 |
| | 105 | • | • | • | • | • | -24 |
| | 120 | 50 | -58 | -0.04 | 95 | 89 | -25 |
| | 135 | 18 | 3 | 0.04 | 94 | 90 | -25 |
| | 150 | 21 | -23 | -0.01 | • | • | -27 |
| | 165 | 7 | 5 | 0.00 | • | • | -25 |
| | 180 | 33 | -39 | 0.01 | 97 | 94 | -27 |
| **72,000 ft.** | 15 | 46 | -26 | 0.06 | 66 | 71 | -5 |
| | 30 | 54 | -31 | 0.06 | 81 | 78 | -14 |
| | 45 | 52 | -35 | 0.05 | 97 | 81 | -31 |
| | 60 | 45 | -36 | 0.03 | 101 | 77 | -40 |
| | 75 | • | • | • | • | • | • |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** EAGLE
**Subject** mrp

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| 60,000 ft | 15 | 32 | -11 | 0.04 | 19 | 41 | |
| | 30 | 34 | -27 | 0.02 | 43 | 54 | -2 |
| | 45 | 32 | -38 | -0.01 | 56 | 62 | -15 |
| | 60 | 29 | -38 | -0.01 | 56 | 61 | -28 |
| | 75 | 25 | -37 | -0.01 | 60 | 62 | -29 |
| | 90 | 36 | -43 | -0.01 | 62 | 64 | -31 |
| | 105 | 38 | -44 | -0.01 | 60 | 62 | -32 |
| | 120 | 40 | -46 | -0.01 | 59 | 62 | -32 |
| | 135 | 35 | -45 | -0.02 | 62 | 64 | -33 |
| | 150 | 42 | -50 | -0.02 | 63 | 66 | -34 |
| | 165 | 42 | -51 | -0.02 | 65 | 67 | -34 |
| | 180 | 40 | -48 | -0.02 | 63 | 63 | -33 |
| 72,000 ft. | 15 | 62 | -36 | 0.03 | 38 | 57 | -18 |
| | 30 | 49 | -46 | -0.01 | 73 | 65 | -37 |
| | 45 | • | • | • | • | • | • |
| | 60 | • | • | • | • | • | • |
| | 75 | • | • | • | • | • | • |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** TLSS
**Subject** mrp

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| 60,000 ft | 15 | 42 | -27 | 0.04 | 38 | 57 | 0 |
| | 30 | 44 | -40 | 0.01 | 65 | 67 | -7 |
| | 45 | 38 | -42 | | 78 | 71 | -22 |
| | 60 | 35 | -43 | -0.01 | 80 | 70 | -34 |
| | 75 | 34 | -42 | -0.01 | 75 | 67 | -37 |
| | 90 | 31 | -41 | -0.01 | 72 | 62 | • |
| | 105 | 22 | -36 | -0.01 | 74 | 63 | • |
| | 120 | 9 | -27 | -0.02 | 77 | 61 | • |
| | 135 | • | • | • | • | • | • |
| | 150 | • | • | • | • | • | • |
| | 165 | • | • | • | • | • | • |
| | 180 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** ATAGS
**Subject** twg

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 3 | 33 | 0.04 | -3 | 26 | 0 |
| | 30 | 6 | 33 | 0.05 | 21 | 34 | -9 |
| | 45 | 3 | 23 | 0.03 | 45 | 40 | -22 |
| | 60 | 10 | 7 | 0.02 | 54 | 45 | -26 |
| | 75 | 9 | 7 | 0.02 | 53 | 43 | -27 |
| | 90 | 8 | 2 | 0.01 | 55 | 41 | -27 |
| | 105 | 12 | 0 | 0.02 | 56 | 43 | -24 |
| | 120 | 19 | 0 | 0.03 | 55 | 46 | -25 |
| | 135 | 19 | 2 | 0.03 | 53 | 46 | -27 |
| | 150 | 15 | 2 | 0.02 | 54 | 47 | -29 |
| | 165 | 19 | -3 | 0.02 | 55 | 46 | -28 |
| | 180 | 22 | -4 | 0.02 | 54 | 45 | -27 |
| **72,000 ft.** | 15 | 18 | 6 | 0.03 | 0 | 32 | • |
| | 30 | 34 | -8 | 0.02 | 18 | 38 | -15 |
| | 45 | 37 | -16 | 0.01 | 27 | 42 | -25 |
| | 60 | 24 | -12 | 0.00 | 47 | 46 | -34 |
| | 75 | • | • | • | • | • | • |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** EAGLE
**Subject** twg

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | • | • | -0.11 | 2 | 23 | -5 |
| | 30 | • | • | -0.11 | 27 | 37 | -12 |
| | 45 | • | -33 | 0.02 | 39 | 41 | -19 |
| | 60 | 22 | -1 | 0.00 | 35 | 41 | -19 |
| | 75 | 32 | -20 | 0.00 | 38 | 41 | -20 |
| | 90 | 14 | 5 | 0.02 | 31 | 36 | -22 |
| | 105 | 50 | -16 | -0.01 | 21 | 37 | -22 |
| | 120 | 53 | 13 | 0.07 | 27 | 44 | -19 |
| | 135 | 34 | -23 | -0.02 | 27 | 43 | -17 |
| | 150 | 52 | 8 | 0.02 | 33 | 41 | -18 |
| | 165 | • | • | -0.11 | 43 | 44 | -22 |
| | 180 | • | -4 | -0.11 | 34 | 41 | -27 |
| **72,000 ft.** | 15 | 19 | 12 | 0.04 | -28 | 48 | -3 |
| | 30 | 33 | -8 | 0.03 | -10 | 54 | -26 |
| | 45 | 36 | -17 | 0.01 | 6 | 55 | -32 |
| | 60 | 41 | -20 | 0.01 | 11 | 53 | -40 |
| | 75 | 47 | -25 | 0.01 | 8 | 51 | -46 |
| | 90 | • | • | • | • | • | • |
| | 105 | • | • | • | • | • | • |
| | 120 | • | • | • | • | • | • |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** TLSS
**Subject** twg

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| 60,000 ft | 15 | 8 | 8 | 0.02 | -13 | 17 | -1 |
| | 30 | 28 | -9 | 0.01 | -7 | 22 | -16 |
| | 45 | 30 | -13 | 0.01 | 15 | 32 | -24 |
| | 60 | 28 | 12 | 0.03 | 15 | 37 | -30 |
| | 75 | 36 | -16 | 0.00 | 15 | 34 | -32 |
| | 90 | 38 | -18 | 0.00 | 12 | 26 | -28 |
| | 105 | 40 | -19 | 0.00 | 7 | 26 | -24 |
| | 120 | 41 | -17 | 0.01 | 8 | 35 | -24 |
| | 135 | 40 | -17 | 0.01 | 9 | 34 | -22 |
| | 150 | 41 | -24 | 0.00 | 10 | 28 | -22 |
| | 165 | 36 | -17 | 0.01 | 16 | 26 | -25 |
| | 180 | 26 | -1 | 0.02 | 12 | 38 | -27 |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** ATAGS
**Subject** wdf

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 5 | 1 | 0.01 | 42 | 54 | 0 |
| | 30 | 8 | 7 | 0.02 | 55 | 60 | 0 |
| | 45 | 13 | 9 | 0.03 | 65 | 64 | -5 |
| | 60 | 12 | 10 | 0.03 | 79 | 69 | -19 |
| | 75 | 15 | 7 | 0.03 | 76 | 70 | -21 |
| | 90 | 16 | 9 | 0.03 | 75 | 69 | -22 |
| | 105 | 17 | 9 | 0.03 | 81 | 71 | -24 |
| | 120 | 18 | 7 | 0.03 | 80 | 73 | -25 |
| | 135 | 18 | 12 | 0.04 | 73 | 70 | -25 |
| | 150 | 21 | 15 | 0.05 | 74 | 70 | -25 |
| | 165 | 21 | 10 | 0.04 | 79 | 72 | -20 |
| | 180 | 18 | 16 | 0.04 | 83 | 71 | -21 |
| **72,000 ft.** | 15 | 24 | 6 | -0.02 | 56 | 61 | -21 |
| | 30 | 31 | -8 | -0.02 | 72 | 68 | -24 |
| | 45 | 29 | -16 | -0.02 | 73 | 62 | -23 |
| | 60 | 58 | -12 | -0.05 | 67 | 62 | -42 |
| | 75 | 43 | -13 | -0.05 | 69 | 60 | -33 |
| | 90 | 28 | -12 | -0.03 | 74 | 57 | -25 |
| | 105 | 35 | -6 | -0.04 | 60 | 55 | -31 |
| | 120 | 37 | -2 | -0.06 | 66 | 59 | -39 |

# Change in cardiac parameters and oxygen saturation
# Rapid Decompressions

**Garment:** EAGLE
**Subject** wdf

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 30 | -20 | -0.02 | 29 | 54 | 0 |
| | 30 | 39 | -17 | 0.00 | 46 | 62 | 0 |
| | 45 | 58 | -22 | 0.00 | 59 | 68 | -6 |
| | 60 | 84 | -29 | 0.00 | 63 | 68 | -14 |
| | 75 | 97 | -31 | 0.00 | 65 | 71 | -18 |
| | 90 | 91 | -12 | 0.05 | 68 | 71 | -25 |
| | 105 | 80 | 1 | 0.07 | 68 | 71 | -28 |
| | 120 | 77 | 13 | 0.08 | 75 | 73 | -28 |
| | 135 | 49 | 31 | 0.12 | 75 | 73 | -27 |
| | 150 | 56 | 25 | 0.11 | 74 | 72 | -27 |
| | 165 | 36 | 44 | 0.14 | 71 | 71 | -28 |
| | 180 | 39 | 36 | 0.12 | 74 | 72 | -27 |
| **72,000 ft.** | 15 | 49 | -2 | 0.05 | 54 | 61 | -3 |
| | 30 | 41 | -13 | 0.03 | 70 | 67 | -2 |
| | 45 | 40 | -15 | 0.02 | 84 | 73 | -11 |
| | 60 | 40 | -20 | 0.01 | 87 | 73 | -20 |
| | 75 | 41 | -24 | 0.00 | 89 | 77 | -26 |
| | 90 | 45 | -28 | 0.00 | 87 | 76 | -30 |
| | 105 | 44 | -29 | -0.01 | 83 | 76 | -42 |
| | 120 | 46 | -30 | -0.01 | 86 | 78 | -40 |

# Change in cardiac parameters and oxygen saturation
## Rapid Decompressions

**Garment:** TLSS
**Subject** wdf

| | Time (s) | HR bpm | SV ml | CI l/min/m2 | SBP mmHg | DBP mmHg | SaO2 % |
|---|---|---|---|---|---|---|---|
| **60,000 ft** | 15 | 30 | -8 | 0.02 | 30 | 48 | 1 |
| | 30 | 39 | -9 | 0.02 | 36 | 53 | 0 |
| | 45 | 58 | -6 | 0.02 | 53 | 56 | -1 |
| | 60 | 84 | 3 | 0.03 | 60 | 60 | -8 |
| | 75 | 97 | -6 | 0.02 | 62 | 61 | -10 |
| | 90 | 91 | -2 | 0.03 | 62 | 59 | -12 |
| | 105 | 80 | 1 | 0.03 | 63 | 60 | -13 |
| | 120 | 77 | • | 0.03 | 63 | 63 | -14 |
| | 135 | 49 | • | • | 62 | 60 | -14 |
| | 150 | 56 | • | • | 56 | 56 | -14 |
| | 165 | 36 | • | • | 58 | 60 | -14 |
| | 180 | 39 | • | • | 70 | 65 | -15 |

William F.X. Casey
Dayton T. Brown, Inc.
Church Street
Bohemia, L.I., N.Y. 11716 .................................... 2

W.L. Epperson
GENTEX Corporation
P.O. Box 315
Carbondale, PA 18407 .......................................... 2

Naval Air Warfare Center Aircraft Division Warminster ........... 26
(24 copies for Code 4.6.4.1)
(2 copies for Code 7.2.5.5)

Commanding Officer
AL/CFTF, ATTN: J. Burns
Brooks AFB, TX 78235 .......................................... 1

S. Dubin
Biomedical Engineering & Science Institute
Drexel University
32nd and Chestnut Sts
Philadelphia, PA 19104 ........................................ 1

L. Hrebien
Electrical and Computer Engineering Department
Drexel University
32nd and Chestnut Sts
Philadelphia, PA 19104 ........................................ 1

H.H. Sun
Electrical and Computer Engineering Department
Drexel University
32nd and Chestnut Sts
Philadelphia, PA 19104 ........................................ 1

Air Force Office of Scientific Research (AFSC)/NL
Bolling AFB, DC 20332-6448 .................................... 1

FAA Civil Aeromedical Institute
Oklahoma City OK 73124 ........................................ 1

NASA Johnson Space Center, Code SP, Houston, TX 77058
ATTN: B. Sauser ............................................... 1

NASA Ames Research Center
Moffott Field, CA 94035 ....................................... 2

Commanding Officer
U.S. Air Force School of Aerospace Medicine
Brooks AFB, TX 78235 .......................................... 1

Commanding Officer
US Army Aerospace Medical Research Laboratory
ATTN: Technical Library
Fort Rucker, AL 36362-5295 .................................... 1

W.D. Fraser
Aerospace Physiology Group
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Ave. West
PO Box 2000
North York, Ontario, Canada, M3M 3B9 .......................... 6

Chief of Naval Operations
Navy Department
Washington, D.C. 20350-2000 .................................. 1

Chief of Naval Operations
Navy Department
Code N-88
Washington, D.C. 20350-2000 .................................. 1

Commander
Naval Safety Center
Naval Air Station
Norfolk, VA 23511 .............................................. 1

Commanding Officer
Naval Aerospace Medical Research Laboratory
Naval Air Station
Pensacola, FL 32508 ............................................ 1

Commanding Officer
Naval Aerospace Medicine Institute
Naval Air Station
Pensacola, FL 32508 ............................................ 1

Superintendent
Naval Postgraduate School
Monterey, CA 93943 ............................................. 1

Commanding Officer
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92138............................................. 1

Commanding Officer
Naval Personnel Research & Development Center
San Diego, CA 92152-6800 ....................................... 1

Commanding Officer
Naval Air Warfare Center
Patuxent River, MD 20670 ....................................... 1

Commanding Officer
Naval Biodynamics Laboratory
P.O. Box 29407
New Orleans, LA 70189 .......................................... 1

Commanding Officer
Naval Submarine Medical Research Laboratory
Naval Submarine Base, New London
Groton, CT 06349 ............................................... 1

Commanding Officer
AL/CFBS, ATTN: B. Albery
Wright-Patterson AFB, OH 45433-6573 ............................ 1

DISTRIBUTION LIST

| | No. of Copies |
|---|---|
| Director<br>Defense Technical Information Center<br>Bldg. 5, Cameron Station<br>Alexandria, VA 22314 .......................................... | 4 |
| Commander, Naval Air Systems Command<br>Naval Air Systems Command Headquarters<br>Code AIR-320R<br>Washington, D.C. 20361-0001 .................................... | 3 |
| Commander, Naval Air Systems Command<br>Naval Air Systems Command Headquarters<br>Code AIR-531TA<br>Washington, D.C. 20361-0001 .................................... | 1 |
| Commander, Naval Air Systems Command<br>Naval Air Systems Command Headquarters<br>Code AIR-5004<br>Washington, D.C. 20361-0001 .................................... | 2 |
| Commander, Naval Air Systems Command<br>Naval Air Systems Command Headquarters<br>Code AIR-5311D<br>Washington, D.C. 20361-0001 .................................... | 1 |
| Office of Naval Research<br>Bioscience Division<br>Arlington, VA 22217-5000 ......................................... | 2 |
| Commanding Officer<br>Naval Medical Research & Development Command<br>Naval Medical Command National Capital Region<br>Bethesda, MD 20814 ............................................. | 1 |
| Commanding Officer<br>Naval Medical Research & Development Command<br>Naval Medical Command National Capital Region<br>Code NMRDC-44<br>Bethesda, MD 20814 ............................................. | 1 |
| Chief, Bureau of Medical & Surgery<br>Navy Department<br>Washington, D.C. 20372 .......................................... | 1 |
| Chief, Bureau of Medical & Surgery<br>Navy Department<br>Code NM&S 3C1<br>Washington, D.C. 20372 .......................................... | 1 |